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The Relative Responsibility of Physical Heat and Micro-organisms for the Hot Weather Rotting of Potatoes in Western India

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The Relative Responsibility of Physical Heat and Micro-organisms for the Hot Weather Rotting of Potatoes in Western India.

(Received for publication on 5th March 1923.)

The storage rots of potatoes have been under study at Poona for several years past and the results of part of the work done up to 1920 have been published in "Bulletin No. 102 of the Bombay Agricultural Department." Among the conclusions reached by the authors (Mann and Nagpurkar and Joshi[1], [2]) are the following:—

(1) A form of rot characterized by a darkening of the tissues, softening of the flesh to a pulp, exudation of watery matter and foul odour, is the most important cause of loss in storage in Western India during the hot weather.

(2) This rot which occurs suddenly and causes wholesale destruction of tubers in the hot weather at temperatures at or above 100° F. is due to physical heat alone and not to any parasite. The name "heat rot" was, therefore, given to this form of rotting.

(3) The symptoms of "heat rot" are a variation, shown by the Italian white round variety of potatoes, of the symptom described as "black heart" of potato tubers by American workers.

(4) That "heat rot" can be prevented by reducing the temperature of storage to 90° F.

The type of rotting alluded to above as "heat rot" had been previously spoken of by the workers at Poona as "black rot,"* a

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[1] Mann, H. H., and Nagpurkar, S. D. The storage of Potatoes. *Bomb. Dept. of Agri., Bull. No. 102, (of 1920).* Ch. IX.

[2] Mann, H. H., and Joshi, B. M. A Chemical Study of "Heat Rot" or "Black Heart" of Potato." *Appendix to Bomb. Dept. of Agri. Bull. No. 102 (of 1920)*

* The term "black rot" was subsequently found used in American literature to describe various kinds of rots like "stem end rot" and field dry rot which occur in the field and not in storage in which the decayed tissues are nearly black in colour when the tubers are taken from the field. This is, however, comparatively a dry rot. See paper on "A Western field rot of the Irish Potato tuber caused by *Fusarium radicicola*" by O. A. Pratt, *U. S. A. Jour. of Agri. Res.*, Vol. VI, No. 9, 1916.

term which brought to mind the striking, blackish discoloration of the tubers above referred to. The almost constant association of a sclerotium-producing fungus with the "black rot" was referred to in Appendix J to the "Annual Report of the Department of Agriculture, Bombay, for 1918-19," where also allusion was made to the differences between "black rot" and "black heart" of the American authors. Mann, Nagpurkar and Joshi were, however, apparently very much impressed by the statement of Bartholomew that a blackish discoloration of the flesh of the potato tuber could result from exposure to temperature of 38°—45° C. (100·4°—113° F.) for 14—48 hours without the intervention of micro-organisms, and, although in the experiments they made with the Italian white round variety of tubers, they did not get the typical "black heart," they seem to have persuaded themselves that the different symptoms which were developed in their tubers were due to differences in susceptibility to typical "black heart," as previously suggested by the American authors regarding American varieties. Mann and Joshi[1] lay special stress on these differences in the following statement:—

"The original description given by Bartholomew in 1913 is absolutely accurate so far as some of our potatoes are concerned, but we would specially draw attention to the great differences that exist between reaction of different varieties to the temperature factor and hence to the production of heat rot."

Impressed, no doubt, by the wide departure from the characteristic symptoms of the American "black heart," the authors have suggested the alternative term "heat rot" for what they believed were purely heat effects on the tubers they experimented with.

The striking differences between American descriptions and figures of "black heart" and those of "heat rot"; the constant occurrence of bacteria and often also of fungi, particularly the fungus *Sclerotium* sp.[2] (previously known as *Rhizoctonia Solani* in India), in potato tubers sent to us as showing "heat rot"; and the occurrence, in our experience, of this type of rotting occasionally at temperatures lower than 90° F. (Pl. I, fig. 1) necessitated a closer enquiry into the nature of the rot.

[1] Mann and Joshi *Ib* p 113.

[2] We are indebted to Dr E. J. Butler, of the Imperial Bureau of Mycology, London (Kew), for informing us that the fungus hitherto known in India as *Rhizoctonia Solani* is really an undescribed fungus and that the one known as *Rhizoctonia destruens* in this country is identical with *Sclerotium Rolfsii*.

Tubers showing this type of rotting were submitted by one of us (S. L. A.) to the Imperial Agricultural Bacteriologist, Pusa, for examination in March 1918, and his report stated that the rot was clearly due to the same or very similar organisms to those already found by him in rotting tubers received from Poona in 1913 and described by him in 1915.[1] These are common soil organisms and probably always present on the surface of the potato tuber. In view of the statement, however, of Mann and Nagpurkar and Joshi[2] that they "made experiments to see whether we had to deal with a parasite" and their conclusion that "we had to deal (in the case of "heat rot") not with an ordinary parasitic attack, whether by fungi or bacteria, but with something which was intimately connected with the rise of temperature," it was considered necessary to determine accurately the relative responsibility of physical heat and of the associated micro-organisms in the causation of the rot described as "heat rot."

The bacteria concerned having been previously studied by Hutchinson and Joshi, the work presented here was limited to testing the action of three of the fungi found most commonly associated with potato rots in Western India and of heat alone on potato tubers.

The general plan of the experiments carried out in this connection was as follows:—Tubers of Italian white, round, variety, looking perfectly healthy and uninjured to the naked eye, were selected, washed with tap water to remove all adherent soil particles and were steeped in a fungicide (for 30 minutes in a 2 per cent. solution of copper sulphate or for 2 hours in a 0·1 per cent. of mercuric perchloride) and dried. These were then divided into convenient lots, each of which was submitted to definite conditions of temperature and infection by an organism. The usual precautions were taken to ensure as far as possible freedom from infection by organisms other than that intended in the experiment. All apparatus used, including the incubator, were sterilized or disinfected as often as was necessary. The inoculations were made (except where stated otherwise) by inserting a bit of a pure culture of the organism into a puncture made on the tuber with sterile needle.

Experiments Nos. 1, 2, 3, 4 and 5 were intended to ascertain the effects of temperature from 95° F. to 100·4° F. (35° C. to

[1] Hutchinson, C. M., and Joshi, N. V. *Mem. Dept. of Agri. Ind., Bact. Ser.*, Vol. I, No. 5, 1915.

[2] Mann and Nagpurkar; Mann and Joshi. *Ib.*

38° C.) acting alone and in presence of the common potato rot fungi—*Sclerotium* sp., *Sclerotium Rolfsii* and *Fusarium* sp. This particular temperature was chosen, as "heat rot" has been stated by Mann and Nagpurkar to occur at temperatures above 90° F. and more commonly at 100° F. or above.

The following tables give the results:—

Experiment No. 1.

19th May to 11th June 1921.

Lot No.	Disinfected with	Temperature	Fungus inoculated	No. of tubers	No of sound tubers at end of experiment	No of rotten tubers	Organisms found in rotten tubers
I		35°-36° C. and kept in moist chamber.	*Sclerotium* sp. (in puncture.)	6	nil	6	*Sclerotium* sp.; bacteria
II		Do.	*Sclerotium* sp. (on eyebud, unwounded.)	6	1	5	*Sclerotium* sp.; bacteria (*Fusarium* in one case)
III		35°-36° C. and kept in dry Chamber	*Sclerotium* sp. (in puncture.)	6	0	6	*Sclerotium* sp.; bacteria
IV	Mercuric perchloride	Do.	*Sclerotium* sp. (on "eye.")	6	3	3	*Sclerotium* sp.
I *a*		Control to I .		6	2	4	*Sclerotium* sp. and bacteria
II *a*		Control to II .		6	3	3	*Sclerotium* sp.; *Fusarium* in 1 case.
III *a*		Control to III .		6	1	5	*Sclerotium* sp. and bacteria
IV *a*		Control to IV .		6	2	4	*Sclerotium* sp.

Remarks.

"Heat rot" occurred whenever *Sclerotium* sp. and bacteria were present; no rotting in the absence of these organisms; *twelve tubers remained perfectly sound after exposure to 35°—36° C. for 23 days; Sclerotium* sp. unaccompanied by bacteria caused dry rot only; apparently sound tubers were found to harbour micro-organisms which escaped surface sterilization. The difference in moisture made no difference in the amount of rotting in the different lots. Lot I*a* showed one case of true "black heart."

Experiment No. 2.

22nd to 26th November 1921.

Lot No.	Disinfected with	Temperature	Fungus inoculated	No. of tubers	No. of sound tubers at end of experiment	No. of rotten tubers	Organisms found in rotten tubers
I	Copper sulphate.	38° C. constant	*Sclerotium* sp.	17	0	17	*Sclerotium* sp. and bacteria.
II		Do	*Sclerotium Rolfsii*	17	17	0	..
III		Do.	*Fusarium* sp causing dry rot	17	16	1	Bacteria only.
IV		Do.	nil (tubers punctured with a needle).	17	17	0	..
V		Do.	nil (tubers unpunctured).	17	17	0	..

Remarks.

Lot I. Blackening of lenticels; darkening and softening of flesh; oozing of brownish liquid and foul smell (=symptoms of "heat rot.")

Lot II. All tubers were externally quite normal and hard; four tubers cut showed a slight enlargement of the puncture, but the fungus had not grown appreciably. No change of colour in flesh.

Lot III. No change of colour in flesh in three tubers cut. (Pl. 1, fig. 3.)

Experiment No. 3.

30th November to 10th December 1921.

Lot No.	Disinfected with	Temperature	Fungus inoculated	No of tubers	No of sound tubers at end of experiment	No of rotten tubers	Organisms found in rotten tubers
I	Copper sulphate.	38° C. constant.	*Sclerotium* sp.	16	0	16	Bacteria only.
II		Do.	*Sclerotium Rolfsii*	16	7	9	*Sclerotium Rolfsii* and bacteria.
III		Do.	Dry rot *Fusarium*	16	0	16	*Fusarium* sp and bacteria
IV		Do.	Nil (tubers punctured).	16	1	15	Bacteria only.
V		Do	Nil (tubers unpunctured).	16	1	15	Bacteria only

Remarks.

Lot I. Tubers blackened, partly or wholly according to degree of rotting; flesh soft and pulpy; brown liquid oozing out; foul odour; flesh pink, pale-yellow or dark when freshly cut; on exposure the pale yellow turns pink and the pink becomes black.

Lot II. Symptoms of wet rot similar to those in Lot I: no blackening of the flesh and no wet rot in the two tubers with only *Sclerotium Rolfsii* in them.

Lot III. Wet rot similar to that in Lots I and II in those cases which had both bacteria and *Fusarium*; no change in colour of the flesh in tubers showing *Fusarium* only in the part free from infection. The fungus acting alone causes only dry rot.

Lots IV and V. Wet rot similar to that in I, II, and III. Controls infected in spite of all precautions.

Experiment No. 4.

1st to 19th December 1921.

Lot No	Disinfected with	Temperature	Fungus inoculated	No. of tubers	No of sound tubers at end of experiment	No. of rotten tubers	Organisms found in rotten tubers
I	Copper sulphate	Maximum 71° F., minimum 60·5 F. (16°-22° C.)	*Sclerotium* sp.	15	2	13	*Sclerotium* sp. and bacteria.
II		Do.	*Sclerotium Rolfsii*	16	0	16	*Sclerotium Rolfsii* and bacteria.
III		Do.	Dry rot *Fusarium*	17	0	17	*Fusarium* sp.
IV		Do.	Nil (punctured)	15	13	2	*Fusarium* sp
V		Do.	Nil (not punctured).	16	16	0	..

Remarks.

Lot I. One of the rotting tubers having both fungus and bacteria showed all the symptoms of "heat rot," *viz.*, pink or black discoloration and softening of flesh, brown liquid oozing out and foul smell. *Note the low temperature at which these symptoms occurred.* The fungus unaccompanied by bacteria causes only a dry rot.

Lot II. The rot had just begun to turn wet in the two tubers; no blackening of tissues.

Lot III. No blackening of tissues.

Lot IV. Infection with *Fusarium* in control in spite of all precautions.

N.B. The punctures in this and the following experiments were closed in every case with paraffin to prevent any further wound infection.

EXPERIMENT No. 5.

15th to 22nd December 1921.

Lot No.	Disinfected with	Temperature	Fungus inoculated	No. of tubers	No of sound tubers at end of experiment	No. of rotten tubers	Organisms found in rotten tubers
I	Copper sulphate.	38° C constant	*Sclerotium* sp.	10	0	10	*Sclerotium* sp. and bacteria.
II		Do.	*Sclerotium Rolfsii*	10	5	5	*Sclerotium Rolfsii*; bacteria and *Sclerotium* sp.
III		Do.	Dry rot *Fusarium*	10	5	5	*Fusarium* sp.; bacteria and *Sclerotium* sp.
IV		Do.	Nil (tubers punctured)	10	6½	4	*Sclerotium* sp.; bacteria.
V		Do.	Nil (not steeped in copper sulphate solution; punctured).	10	5½	5	*Sclerotium* sp.; bacteria.

Remarks.

Lot I. The rot was wet only in the presence of bacteria and in advanced stages showed all the symptoms included in the term "heat rot."

Lot II. *Sclerotium* sp. was found in some of the infected tubers, although not originally introduced. This fungus was found only in those tubers that showed external blackening.

Lot III. The inoculated fungus had not grown in the five tubers that remained sound. The other five showed blackening of the skin and flesh associated with *Sclerotium* sp. and oozing of brown liquid with foul smell in some cases.

Lot IV. Blackening of skin and flesh associated with *Sclerotium* in three tubers.

Lot V. One of the tubers showing *Sclerotium* sp. and bacteria had soft flesh which was pink when freshly cut and became blackened on exposure.

N.B. The appearance of *Sclerotium* sp. in Lots II, III, IV and V suggests that the tubers in this experiment were perhaps already infected with this fungus though the fungus escaped notice as well as the surface sterilization.

It will be seen from these results that whenever temperature alone has acted, there has been no rot even though the tubers had been exposed to 38° C. for from four to ten days. Symptoms of "heat rot" occurred only in the presence of micro-organisms, and their occurrence in Experiment No. 4 in Lot I at the low temperature (between 16° C. and 22° C. = 60° - 71° F. roughly) shows that temperature cannot be the primary cause of these symptoms.

It will be also seen from the above results, particularly from those of Experiment No. 5, that there is reason to suspect the existence of previous infection even in apparently sound tubers, especially with the fungus *Sclerotium* sp. In experiment after experiment in the course of our work on potato rots this fungus appeared in tubers selected as apparently sound and treated with copper sulphate or mercuric perchloride to destroy any surface infection and thus confirmed the statement of Mann and Joshi[1] that "it is often difficult, if not impossible, to eliminate *Rhizoctonia* fungus (*R. Solani*) which often grows, in spite of all surface sterilization, just under the skin." The presence of this fungus and of bacteria, which escape surface sterilization of potato tubers, seems to have largely vitiated the results of Mann and Joshi's work on "heat rot" and makes it extremely difficult to study satisfactorily the pure heat effect. But the observation that all the fungi concerned, including *Sclerotium* sp., practically cease to grow at the temperature of 40° C. made it possible to exclude their action and also to a large extent of bacteria, the optimum temperature for growth of the rot-causing ones being below 40° C. as found by Hutchinson and Joshi.[2] To determine the effect of heat alone, therefore, Experiments Nos. 6 and 7 were made, in which tubers were subjected to temperatures of 40° C. and 41° C. (= 100·4 - 105·8° F.) with and without inoculation with *Sclerotium* sp. which had been found to be the most commonly associated fungus, in addition to bacteria, in cases of "heat rot."

In Experiment No. 7; a modification was made to determine the effect, if any, of subjecting tubers to the high temperature of 41° C. (105·8° F.) for four days and then removing them to dry and moist conditions respectively at the low laboratory temperatures of 16° C. to 22° C. (= 60° - 71° F. roughly). The idea was to imitate the conditions supposed to be brought about by sudden rises of temperature in potato storage heaps due to high

[1] Mann and Joshi *Ib*, p 111.
[2] Hutchinson, C. M., and Joshi N. V. *Ib.*

summer temperatures prevailing for only a few days and the subsequent return to normal, comparatively low temperatures, and to determine if heat as such acting intensively for a short period could bring about any alteration of the tissues of the potato tuber which could be recognized as "heat rot." Some lots were also dipped in paraffin to combine exclusion of air with heat action, *following Mann and Joshi who had treated some of their tubers* in this manner in their study of "heat rot." The results are given in the following tables:—

EXPERIMENT No. 6.

21st January to 4th February 1922.

Lot No.	Disinfected with	Temperature	Fungus inoculated	No of tubers	No. of sound tubers at end of experiment	No of rotten tubers	Organisms found in rotten tubers
I	Mercuric perchloride.	40° C constant	*Sclerotium* sp.	16	4	11 rotten and 1 showed true "black heart" (Plate II, fig. 6).	*Sclerotium* sp.; bacteria
II		Do.	Nil (tubers punctured)	14	4	10	Do.
III		Do.	Nil (not punctured).	16	6	10	Do

Remarks.

Lot I. Dry rot only when *Sclerotium* sp. was alone present. Blackening of lenticels extending gradually over the rest of the skin again occurred in association with *Sclerotium* sp.; symptoms of "heat rot" occurred whenever bacteria were present in addition to the fungus. The four sound tubers were removed from the incubator on 23rd, 27th and 31st January and 2nd February respectively, *the last one remaining normal after twelve days' exposure to 40° C.*

Lot II. Skin of tubers blackened; tubers showing varying degrees of softness only when bacteria were present. The four sound tubers were removed from the incubator on 23rd, 25th and 27th January and 2nd February respectively. *The last one thus remained normal even after twelve days' exposure to 40° C.*

Lot III. Blackening of skin and flesh in all tubers; softening of flesh occurred only when bacteria were present in addition to the fungus. Of the sound tubers two were removed from incubator on 23-1-22, two on 25-1-22, one on 27-1-22 and one on 31-1-22. *The last one, therefore, remained normal after nine days of exposure to 40° C.* (Plate II, fig. 5.)

EXPERIMENT No. 7.

23rd February to 16th March 1922.

Lot No	Disinfected with	Temperature	Fungus Inoculated	No of tubers	No of sound tubers at end of experiment	No. of rotten tubers	Organisms found in tubers
I		41° C constant	*Sclerotium* sp.	12	12	0	..
I a		41° C. constant from 23rd to 27th February 1922 and after that the room temperature (between 16° to 23° C), and kept *moist*.	Do	12	0	12	*Sclerotium* sp and bacteria.
I b		41° C constant up to 27th February 1922, thereafter room temperature (16° to 23° C), kept *dry*.	Do	12	0	12	Do
II		41° C. constant	Punctured but not inoculated.	12	12	0	..
II a	Mercuric perchloride	41° C *from* 23rd to 27th February 1922 thereafter room temperature (16°-23° C), kept *moist*.	..	12	5	7	*Sclerotium* sp and bacteria
II b		Similar to II a; kept *dry*	..	12	3	9	Do.
III		41° C. constant	Not inoculated and not punctured. Dipped in paraffin	13	2	10	Bacteria
IV		Do	Uninoculated and unpunctured. Not paraffined.	12	11	1	Do.
III a		Room temperature (16°-23° C.)	Same as III	12	8	4	*Sclerotium* sp., *Fusarium* and bacteria
IV a		Do.	Same as IV	12	7	5	*Sclerotium* sp. and bacteria

Remarks.

Lot I. Sound tubers removed from incubator on 4-3-22, *i.e.*, after nine days' exposure to 41° C.; the inoculated fungus made no growth.

Lot Ia. All the tubers had remained perfectly hard and normal in appearance till 27-2-22, *i.e.*, after four days of exposure to 41° C.; on 16-3-22 they all were rotten at low room temperature, the rot being a wet one and showing all the symptoms of "heat rot."

Lot Ib. Same remark as for Lot Ia: tubers were all sound up to 27-2-22 and all of them were found rotten on 13-3-22.

Lot II. Tubers remained sound and normal till 4-3-22 when they were removed from incubator; exposure to 41° C. for nine days did not cause any rotting or discoloration in the absence of micro-organisms.

Lot IIa. No change in tubers as long as they were at 41° C.; rotting similar to that in Lots Ia and Ib.

Lot IIb. No change in tubers until removed from incubator; rotting similar to that in Lots I and Ib.

Lot III. The two sound tubers were removed from the incubator on 24th and 25th February respectively and showed no abnormality; the others blackened from the fourth day and drops of brown liquid were exuded from lenticels; blackening of flesh occurred, but the softening was not very pronounced on 4-3-22, the date of cutting.

Lot IV. Eleven tubers remained normal till 4-3-22 when they were examined.

Lot IIIa. Tubers examined on 4-3-22 and 5-3-22; blackening of tubers externally and internally; flesh softened.

Lot IVa. Blackening of lenticels and symptoms of "heat rot" in some tubers. Note the low temperature at which these occur.

It will be seen from the above that potato tubers may remain perfectly sound and normal even after exposure to temperature of 40° C. for twelve days and to 41° C. for at least nine days if micro-organisms are successfully excluded and if the tubers are originally free from infection (Pl. I, fig. 2). The development of *Sclerotium*, sp. in tubers not deliberately infected with it again points to widespread infection with this fungus of apparently sound tubers and to the difficulty of excluding it by surface sterilization. Its action is seen to be entirely inhibited, however, at 41° C. as shown by the behaviour of Lots I, II, III and IV in Experiment No. 7; any rot-

ting taking place at 41° C. appears to be due to bacteria alone The behaviour of Lots I*a*, II*a*, and II*b* in Experiment 7 is particularly interesting. In all of these the tubers kept perfectly well for four days though exposed to 41° C. But on removal to laboratory temperature there was considerable rotting, but it is to be noted that this occurred only in association with micro-organisms. That this could *not* have been due to any purely heat effect apart from the action of bacteria is shown by the five sound tubers in II*a* and three sound tubers in II*b* which had been subjected to similar heat action but had remained free from micro-organisms.

The moist or dry conditions in which these lots were placed after exposure to 41° C. did not seem to make any difference in the amount of rotting which seemed to be related rather to the amount of previous infection.

In the case of Lots III and IV which had been dipped in paraffin and exposed to 41° C. the symptoms described by Mann and Joshi[1] in their similar experiments were noticed in some cases but not in all, and in every case where softening and rotting of the tuber occurred bacteria were clearly seen in the tissues (Pl. I, fig. 4).

In all the above experiments it was rather remarkable that the true "black heart", as understood by Bartholomew and other American writers[2], [3] was not produced except in one or two tubers (Pl. II, fig. 6) in the variety we worked with (Italian white round, such as was available in the Poona market in the season of 1921-22 and which was described to us as the produce from the first lot of Italian seed tubers imported into India after the war). In order, therefore, to see if the true "black heart" is produced in any of the other varieties available by simple exposure to high temperatures, eleven varieties were subjected to a temperature of 42° C. for from two to nine days. The typical "black heart" was developed in the case of some of the varieties (Pl. III, fig. 7) but not in all.[4] In none of the eleven varieties, however, did any rotting occur even after exposure for nine days at 42° C. and no organisms were found and the tubers remained normal externally

[1] Mann and Joshi *Ib.*, p. 132

[2] Bartholomew, E. T. *Phytopathology*, Vol. III, p. 180, 1913; A pathological and physiological study of the Black Heart of Potato Tubers *Centrbl Fur. Bakt*, 43 Bd., No. 19-24, 1915, pp. 609-639

[3] Stewart and Mix. *N. Y. Agri. Expt. Sta*, *Bull* 4?6, 1917.

[4] This experience is not in agreement with that of Bartholomew who, experimenting with sixteen varieties, concluded that all varieties of the potato, when subjected to a temperature of 38-48°C. for 15 to 20 hours, would develop "balck heart" Bartholomew, E. T. *Loc. cit.*

and internally (except, of course, in the cases of "black heart"), this result again showing that micro-organisms and not heat are the primary cause of potato rots.

In discussing the effects of simple heat unaccompanied by micro-organisms it is relevant to state that the experience of Mann and Joshi, that "at 36° C. changes occurred in the tissues of the potato tuber regularly, causing them to soften and blacken and rot in about 12 days," occurred to us also when we were working at this somewhat low temperature (Experiment No. 1) but the rotting, though general, did not occur in the case of every tuber, and even Mann and Joshi[1] record the fact that "one or two in every set of twelve (tubers exposed to 36° C.) remained hard or rather increased in hardness." The tubers that remained sound in our experience although exposed to about 36° C. were found to be free from fungi and bacteria, while those that were rotten invariably showed bacteria and almost always the fungus *Sclerotium* sp. also. It is reasonable to suppose that the one or two tubers which remained hard in every set of twelve in Mann and Joshi's experiments did so because they were free from micro-organisms, while the others rotted because many of them had admittedly the fungus (*R. Solani*) and presumably also bacteria, from the frequent allusions to bacterial activity in the descriptions and interpretations of their results.[2] The statement of Mann and Joshi, on the other hand, that "at 41° to 42° C. the degeneration (of potato tubers) was very rapid and within two days the tissues were darkened and in 6 days the tubers were completely soft and rotten" was not borne out in our experiments when and as long as bacteria were successfully kept out. In other words, no rotting occurred in our experience apart from micro-organisms, and whenever these were excluded the tubers remained practically unaltered even by the high temperature of 42° C. The inference, therefore, follows that heat by itself in the absence of micro-organisms is not responsible for the symptoms described as "heat rot." As a matter of fact, these symptoms have actually been more easily produced in our experience at temperatures at or about 36° C, which is nearly the optimum for the growth of the associated micro-organisms than at 42° C. which is above that optimum. Pl. I, fig. 1 shows the symptoms of "heat

[1] Mann and Joshi. *Ib.*, p. 114

[2] For example, the following statements in *Bull. No. 102*: P. 120, "The sudden rise (in amount of soluble matter) after 14 days at 36°C. is obviously due to other causes and probably to the presence of bacterial rots." P. 127, "The potato was soft and oozing before the 14th day and we think (though we have no proof) that the later rise in amount of catalase is due to entrance of bacteria."

rot" produced in tubers kept at laboratory temperature not exceeding 81° F. in the month of February 1922 in consequence of attack by micro-organisms. These latter, therefore, and *not* heat must be regarded as the true cause of the so-called "heat rot."

The correctness of identifying "heat rot" with "black heart" may now be briefly considered. The original descriptions of "heat rot" and "black heart" are quoted below :—

Heat Rot.[1]

"The flesh of the potato, generally on one side, but sometimes in the centre, takes in a pinkish tinge. This spreads over nearly all the tuber before any further appearance is noted. Then at any part of the tuber, but often near the centre, a small patch of dull dark colour appears, soft to the touch and in which, obviously, degeneration of the contents of the cells is taking place. At a temperature of 36° C. the changes to this part usually take about six days. Most of the potatoes at this stage have become soft, but one or two in every set of twelve remained hard or rather increased in hardness. After this stage is reached further degeneration is rapid, and by the twelfth day the whole potato is greyish black in colour, very soft and pulpy, often with watery matter oozing out, and it smells badly."

Black Heart.[2]

"Black heart is the name proposed by Bartholomew for an abnormal condition of potato tubers in which the central portion is dark brown or black. Affected tubers may appear normal externally, but when cut open they show an area of dead black tissue occupying a large portion of the interior. Frequently the trouble takes the form of a cavity lined with a thick layer of tough, dead, black tissue."

These descriptions have very little in common. The American authors do not allude to any *rotting* in connection with "black heart." A comparison of the figures of "heat rot" and "black heart" (Plate III, figs. 8 and 9) does not suggest any similarity between the two either. The contention that "heat rot" is a mere variation of the symptoms of "black heart" exhibited by a particular variety seems hardly tenable inasmuch as true "black heart" has been noticed in the Italian variety in a few cases. "Black heart," moreover, can be produced in the absence of micro-

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[1] Mann and Joshi. *Ib*, p. 114.
[2] *N. Y. Agri. Expt. Sta. Bull. No. 4?6* 1917, p. 323

organisms, while "heat rot" has been shown to occur only in their presence.

The evidence and arguments advanced by Mann and Nagpurkar in support of their opinion that "heat" and not organisms is the main cause of the rotting may be very briefly considered before concluding this paper.

Mann and Nagpurkar state on p. 84 of their Bulletin," The rotting often comes on so suddenly when the temperature rises and involves so completely a bag or a consignment of potatoes, that it is difficult to believe that any or even all the above causes (fungi and bacteria) were the main source of the rot which was liable to cause such tremendous destruction and loss." The mere suddenness of the rotting should not be a matter of surprise to any one acquainted with the rapidity of multiplication of bacteria, and it certainly cannot be regarded as sufficient reason to exclude fungi and bacteria as causes of the rot in the absence of detailed experimental evidence. Although the authors state that "they made experiments to see whether we had to deal with a parasite," the very scanty details given do not show that beyond "burying sound tubers in soil with rotting ones," or "cutting sound tubers with a knife just used to cut a rotting tuber," or "watering them with the watery oozings from an affected potato" any efforts were made to test the parasitism of the organisms concerned, and even of the experiments just mentioned no details as to the conditions of the experiments or the length of time they lasted, have been given. It is, therefore, not at all easy to follow the authors to their conclusion that "no other parasite (than *B. Solani*) is usually present and the "black heart" or "heat rot" is in no way infectious" Hutchinson and Joshi's work with bacteria and our own work with the fungi have proved the parasitism of a number of the organisms associated with potato rots, and further work, especially with bacteria, may prove the parasitism of more. The possibility of the ordinarily saprophytic organisms becoming pathogenic at higher temperatures has also to be reckoned with. Cotton and Taylor[1] state that the common saprophytic bacteria *Bacillus subtilis* and *B. vulgatus* are known to become pathogenic at a temperature of about 95° F. to various plants, amongst others the potato.

In conclusion, the practical bearing of the results of this investigation on the problem of potato storage in Western India may be

[1] Cotton, A. D., and Taylor, H. V. Supplement (No. 18) to the *Jour. Board of Agri.* London, March 1919, p. 52.

very briefly indicated. It has been shown that the production of "heat rot" is dependent on the presence of certain micro-organisms, particularly bacteria, and not on whether the temperature of storage is above or below 90° F. as previously supposed. The unreliability of the common fungicides—copper sulphate and mercuric perchloride—as means of disinfecting potato tubers has also been demonstrated. In view of the optimum limits of temperature for the growth of the bacteria and fungi associated with "heat rot" which are from 20° to 37° C. (68° to 100° F. roughly) as found by Hutchinson and Joshi for the bacteria and for the fungi by ourselves, it seems desirable to still further reduce the temperature of storage (at least to 20° C =68° F.) to ensure freedom from potato rots.

Summary of conclusions.

(1) Physical heat up to 42° C (107·6° F.) by itself acting on potato tubers continuously for a period of at least *nine days* causes no rotting in the absence of micro-organisms.

(2) The symptoms described by Mann and Joshi and Nagpurkar as "heat rot" occur only in the presence of micro-organisms, especially bacteria, and may be produced at low temperatures (between 60° and 71° F.) if the appropriate micro-organisms are present. Temperature, therefore, cannot be the primary cause of the so-called "heat rot."

(3) The identification of the "black heart" of potatoes described by American authors with the "heat rot" is shown to be incorrect.

(4) Different varieties of potatoes differ considerably in susceptibility to "black heart" on exposure to temperatures between 38° to 42° C. Some may remain normal even after nine days' exposure to 42° C. continuously.

(5) In view of micro-organisms being the primarily responsible factor in the causation of "heat rot," reduction of the temperature of storage to 90° F. cannot alone be relied on to ensure freedom from this form of rotting, as previously believed.

(6) Apparently sound potato tubers may harbour the organisms concerned in the production of "heat rot" and these latter often escape surface-sterilization of tubers with fungicides like copper sulphate and mercuric perchloride. These fungicides, therefore, cannot be entirely relied on to prevent rotting in storage.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Symptoms of "heat rot," softening and blackish discoloration of flesh and watery matter oozing out; produced at temperature not exceeding 81° F.

Fig. 2. Tubers from experiment No. 7 of 23rd February 1922, exposed to 41° C. for nine days.

Fig. 3. Tubers from experiment No. 2 of 22nd November 1921, exposed to 38° C. for four days.

Lot I. Inoculated with *Sclerotium* sp. (Note symptoms of "heat rot.")

Lot II. Inoculated with *Sclerotium Rolfsii*.

Lot III. Inoculated with dry rot *Fusarium* sp.

Lot IV. Not inoculated. (Control.)

Fig. 4. Tubers from experiment No. 7, dipped in paraffin and exposed to 4? C. for nine days.

PLATE II.

Fig. 5. Tubers from experiment No. 6 of 21st January 1922, exposed to 40° C. for six days.

Lot I. Inoculated with *Sclerotium* sp.

Lot II. Punctured but not inoculated.

Lot III. Not punctured, not inoculated.

Fig. 6. "Black heart" in Italian white round potato.

1. Picked from store. (This has *Fusarium* dry rot i addition.)
2. From experiment No. 6 of 21st January 1922.

PLATE III.

Fig. 7. Susceptibility to "black heart" in different varieties of potato, tubers exposed to 42° C. for nine days.

29 = Iron Duke variety.

33 = Queen Mary variety.

34 = Up-to-date variety.

30 = Irish Queen variety.

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